Measurement and Verification of Savings in Combined Heating and Power Projects

John A. Shonder

Oak Ridge National Laboratory

Motivation for this work

- Federal customers interested in combined heating and power for their sites
  - Reduce energy costs
  - Improve reliability of electric supply
- ESPC (including UESC) is often the best (sometimes the only) way to implement these projects given lack of appropriated funds for capital improvements
- M&V required to ensure guaranteed savings are delivered
- Federal customers should be driving development of M&V plan, but often are not
  - Lack of experience/training/interest
  - Sometimes seen as added expense/headache
  - Thus it is often left to Core Teams, PFs and the ESCO to ensure quality of M&V plan

Federal ESPC Task Force has recommended development of M&V templates. Their reasoning:

- *Lack of experience at the installation level: Installation and sometimes HQ may lack expertise or experience in M&V.*
- *General template would simplify the development process and review processes.*
- *A standard template by ECM would simplify the ESCO's response on the M&V process.*
- But CHP is not a single ECM, so a number of standard templates may be required

CHP systems encompass a wide variety of technologies

- Electrical generation
  - Combustion turbine
  - Microturbine
  - Fuel cell
  - Engine/generator
- Thermal end-use
  - Direct use of steam for heating
  - High/low temperature hot water for heating
  - Chilled water production via absorption chiller
  - Desiccant regeneration
  - Process loads
- Rate structure impacts M&V plan as well
- Difficult to specify “one size fits all” M&V plan

FEMP’s M&V Guideline v2.2:

- “Measurement and verification plans for cogeneration projects will need to be custom developed by the ESCO and the federal agency since each project is usually unique and there are no guideline M&V methods (as there are for water and energy measures).”

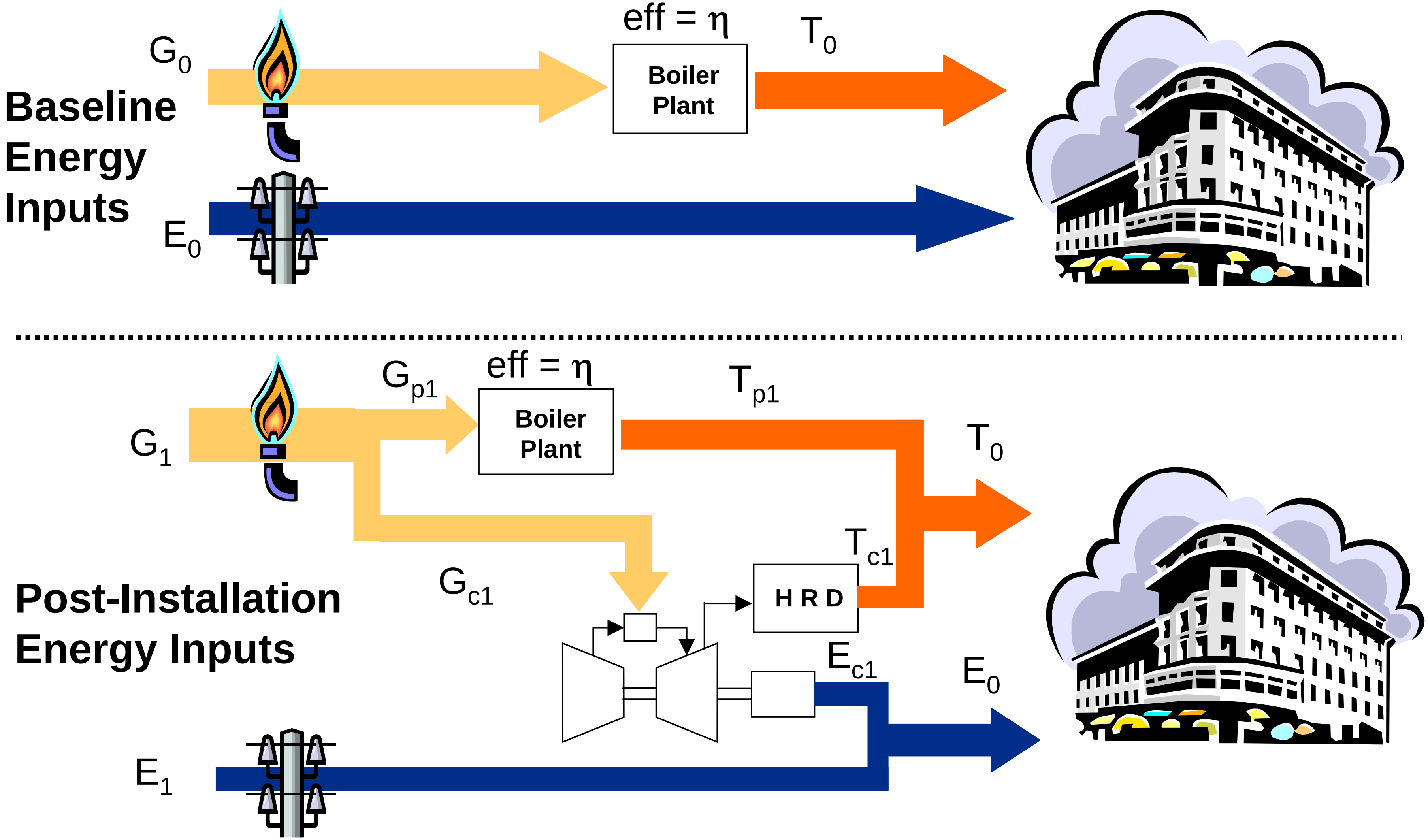
Resources currently available for developing M&V plans for CHP projects

- FEMP M&V Guidelines v2.2, Chapter 34, *Cogeneration Projects*
  - One-for-One Replacement
  - Net Energy Use Analysis
- IPMVP
  - Volume III, “[..] Determining Energy Savings in Renewable Energy Technology Applications”
  - “Developing a M&V Protocol for Distributed Generation Technologies” (11/03 Draft)
- ASHRAE Guideline 14-2003
  - No specific CHP cases, but very useful information

One-for-One Replacement

- Assumes energy produced by the CHP system displaces energy that would have been provided by an existing source
- Energy savings is equal to the economic value of the net energy production by the CHP system
- O&M cost of the CHP system is also a consideration

Determining savings from a simple CHP system: One-for-one replacement



Definition of variables

- Baseline:
  - G_0 : Natural gas purchased from utility
  - E_0 : Electrical energy purchased from utility
  - T_0 : Thermal load
- Post-installation
  - G_1 : Natural gas purchased from utility
  - E_1: Electrical energy purchased from utility
  - G_{p1} : Gas used by boiler plant
  - G_{c1}: Gas used by turbine
  - E_{c1} : Net electrical output from turbine (i.e., after parasitics)
  - T_{c1}: Thermal output from CHP system
  - T_{p1}: Thermal output from boiler plant

Energy cost savings is baseline cost minus post-installation cost

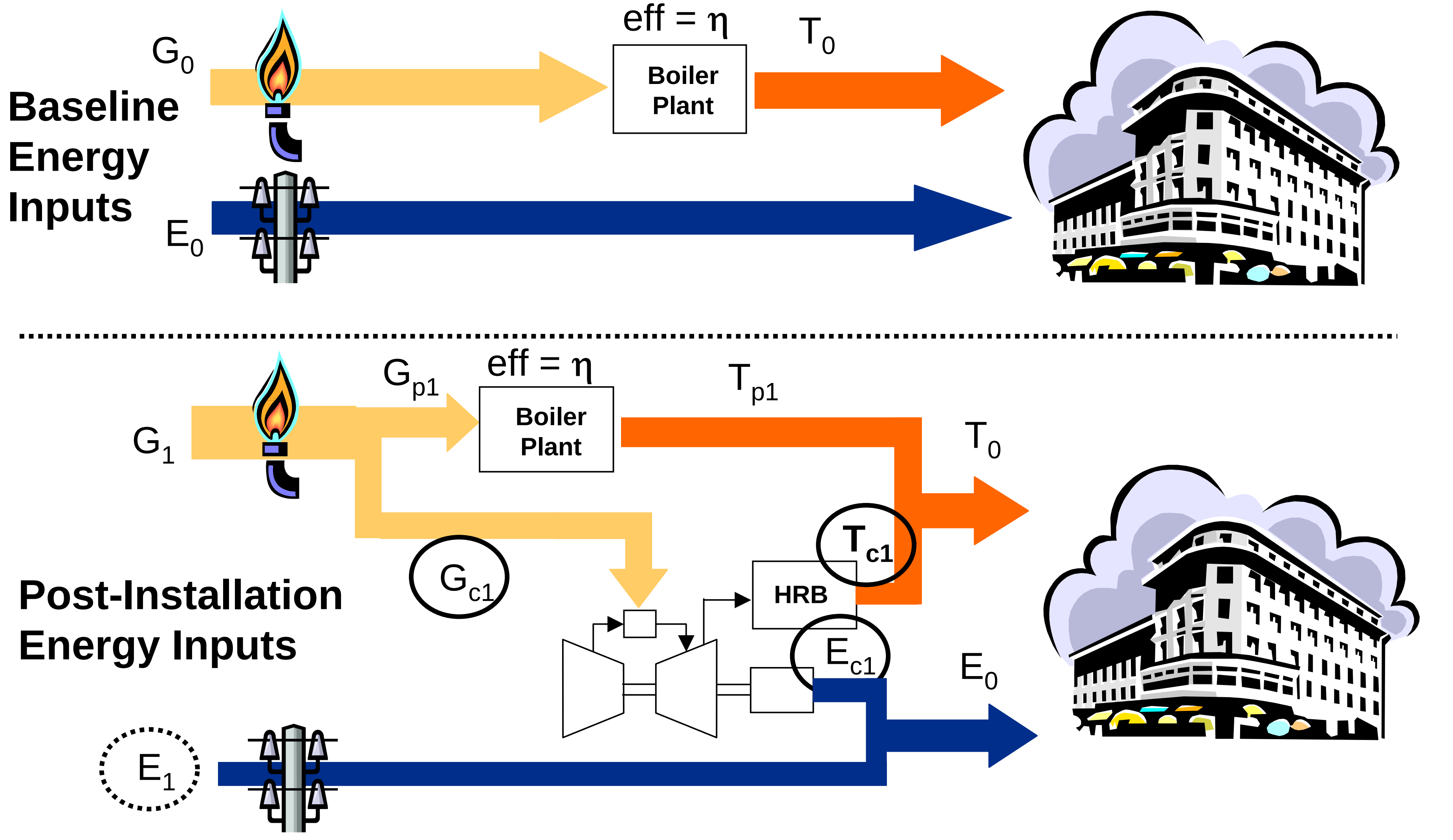
- Savings = [Cost(E_0)+Cost(G_0)]
  - [Cost(E_1) +Cost(G_1)]
- In terms of things that can be measured:

Savings = Cost(E_{c1}) + Cost(T_{c1}/η) – Cost(G_{c1})

= { Value of generated electricity } + { Value of displaced natural gas } – { Cost of natural gas used by CHP }

- This simple approach does not consider demand charges, which often drive the economics
- O&M costs are also a factor in project economics as with any ECM

Three measurements are required at a minimum



One-for-One Replacement can be thought of as Option B, Continuous Measurement

- Measure gas input to generator
  - Gas meter totals fuel input to generator
  - Multiply total by per therm cost of natural gas
- Measure electric output from generator
  - Electric meter reads total kWh sent from generator
  - Multiply by electric cost per kWh*
- Measure thermal output from heat recovery boiler
  - Water inlet/outlet temperatures and flow rate
  - $Q = 500 \times \text{gpm} \times \Delta T$
  - Determine how much gas the boiler would have used to produce this amount (Q/η)
  - Multiply by gas cost per therm

Of course, determining the efficiency of the gas boiler may not be easy

- Previous slide assumed that by measuring flow and temperature rise of water through heat recovery device, we could determine how much natural gas the boilers would use to produce same amount of heat
- Efficiency may vary with load (e.g., multiple boilers operating in stages) requiring
  - Modeling/Engineering calculations
  - Stipulation of efficiency if data is lacking

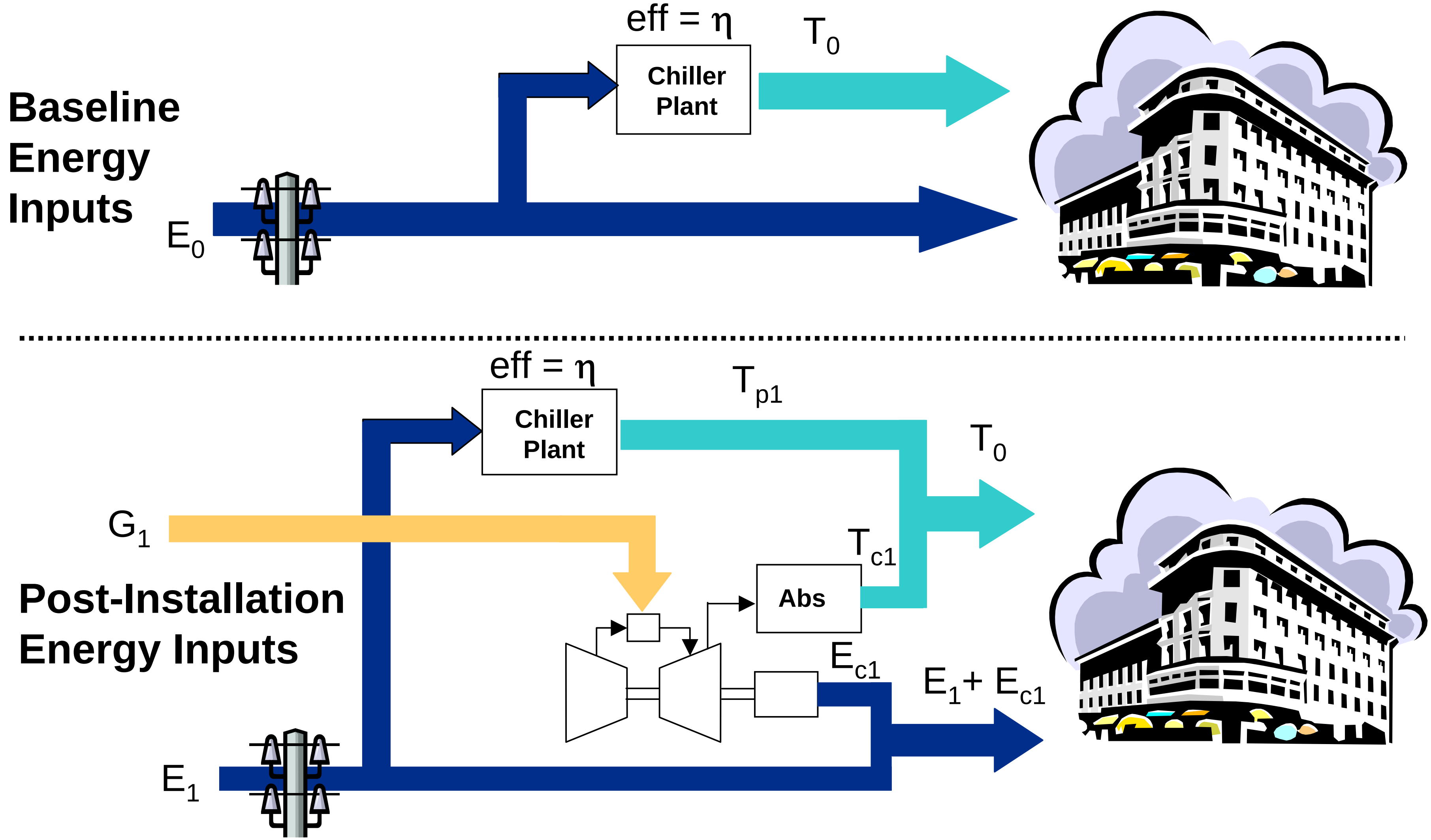
Determining the value of generated electricity E_{c1} may be difficult as well

- Some rate structures include
  - Demand charges with ratchet
  - Block electrical rates
  - Time of day rates
- Electrical production from CHP cannot be priced in isolation
- One possibility is to price the total electrical load
- This amounts to reconstructing what the utility bill would have been in the absence of CHP

Pricing the total electrical load

- Record E_{c1} and E_1 at 15-minute-intervals
- Add E_{c1} and E_1 to determine total facility electrical demand
- Use applicable rate structure to determine cost if all electrical energy had been delivered by utility
- Value of E_{c1} is hypothetical utility bill minus actual utility bill
- Note that this incorporates all standby charges, interconnect fees, rate renegotiations

Waste heat may also be used to displace electrical energy



Here it is more difficult to determine the economic value of the displaced energy

- Savings = $[\mathrm{Cost}(E_0)+\mathrm{Cost}(G_0)]$

  $- [\mathrm{Cost}(E_1) + \mathrm{Cost}(G_1)]$

  $= \mathrm{Cost}(E_{c1}) + \mathrm{Cost}(T_{c1}/\eta) - \mathrm{Cost}(G_{c1})$
- kW/ton (η) of electric chiller depends on outdoor air temperature and load, so efficiency changes minute-by-minute
- The more complicated the calculations, the less confidence one has in them
- Other approaches may be warranted

One option is to stipulate this portion of the savings

- Use engineering calculations to estimate displaced electrical load due to reduced chiller load as a function of chilled water production and outdoor air temperature
- Stipulate an annual value based on typical year conditions; calculate annually based on actual conditions and compare
- Can also use Net Energy Analysis

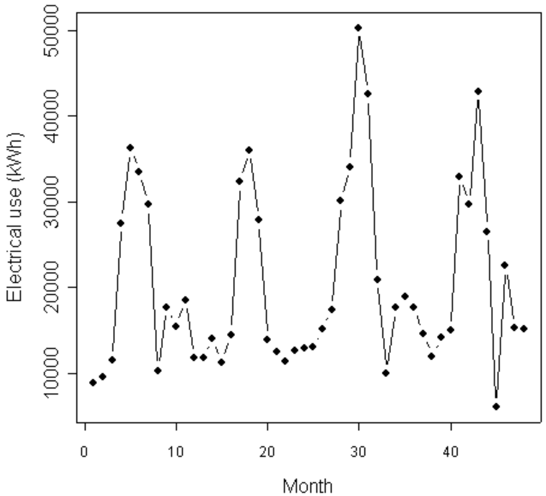
Net Energy Use Analysis: Similar to Option C

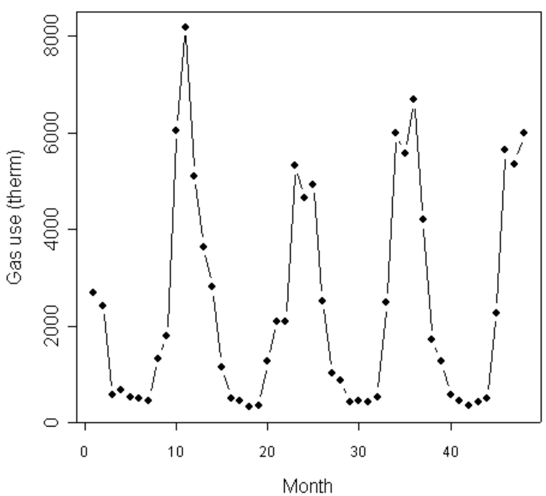
- Develop a model of baseline energy use
  - Relate electrical energy and gas use to weather and other variables
- Post-installation:
  - Use baseline formula to determine energy that would have been consumed during the period
  - Subtract actual energy use to determine savings
- As always, Savings = [Cost(E_0)+Cost(G_0)] - [Cost(E_1)+Cost(G_1)] but here we estimate E_0 and G_0

Example system

- Small residential area consisting of 40 homes
- Air conditioning with central air units
- Heating with gas furnaces
- Gas water heaters
- Four years of data available

Step 1: Correlate baseline gas and electric use to heating/cooling degree-days and days per billing period





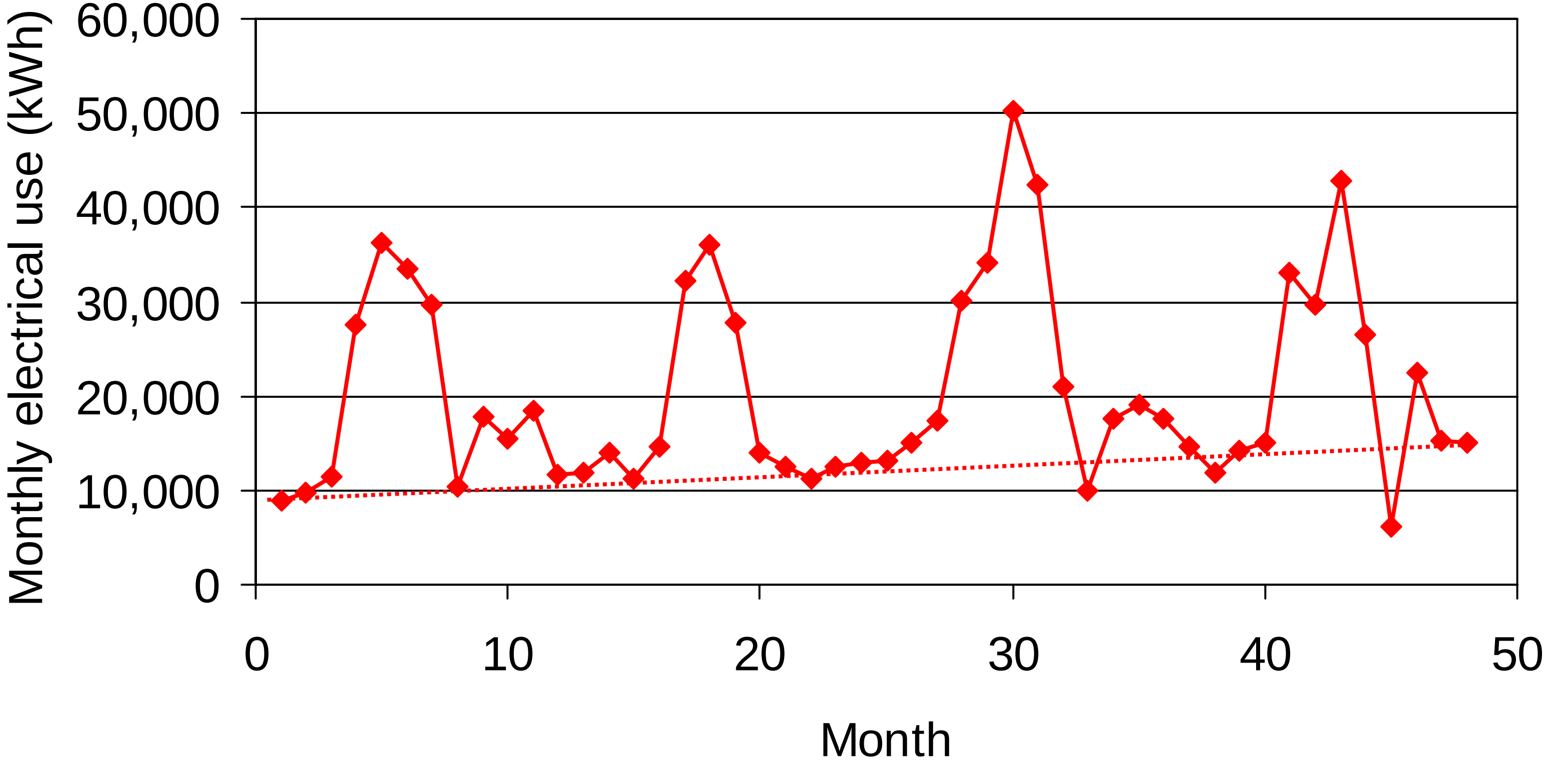
$E_0 = (325.8+3.49n) \times \text{ndays} + 133.0 \times CDD_{71} + 3.23 \times HDD_{64}$

$G_0 = 14.48 \times \text{ndays} + 7.04 \times HDD_{64}$

These are not simple regressions

- Note that the models depend on:
  - Number of days in billing period
  - CDD and HDD to base temperatures determined from the data (not pre-determined)
- Development of models like these requires specialized software (Excel generally won’t do)
- Variable-base degree day calculations require access to daily average temperature data
- Consult ASHRAE Guideline 14-2002 Annex D, “Regression Techniques”

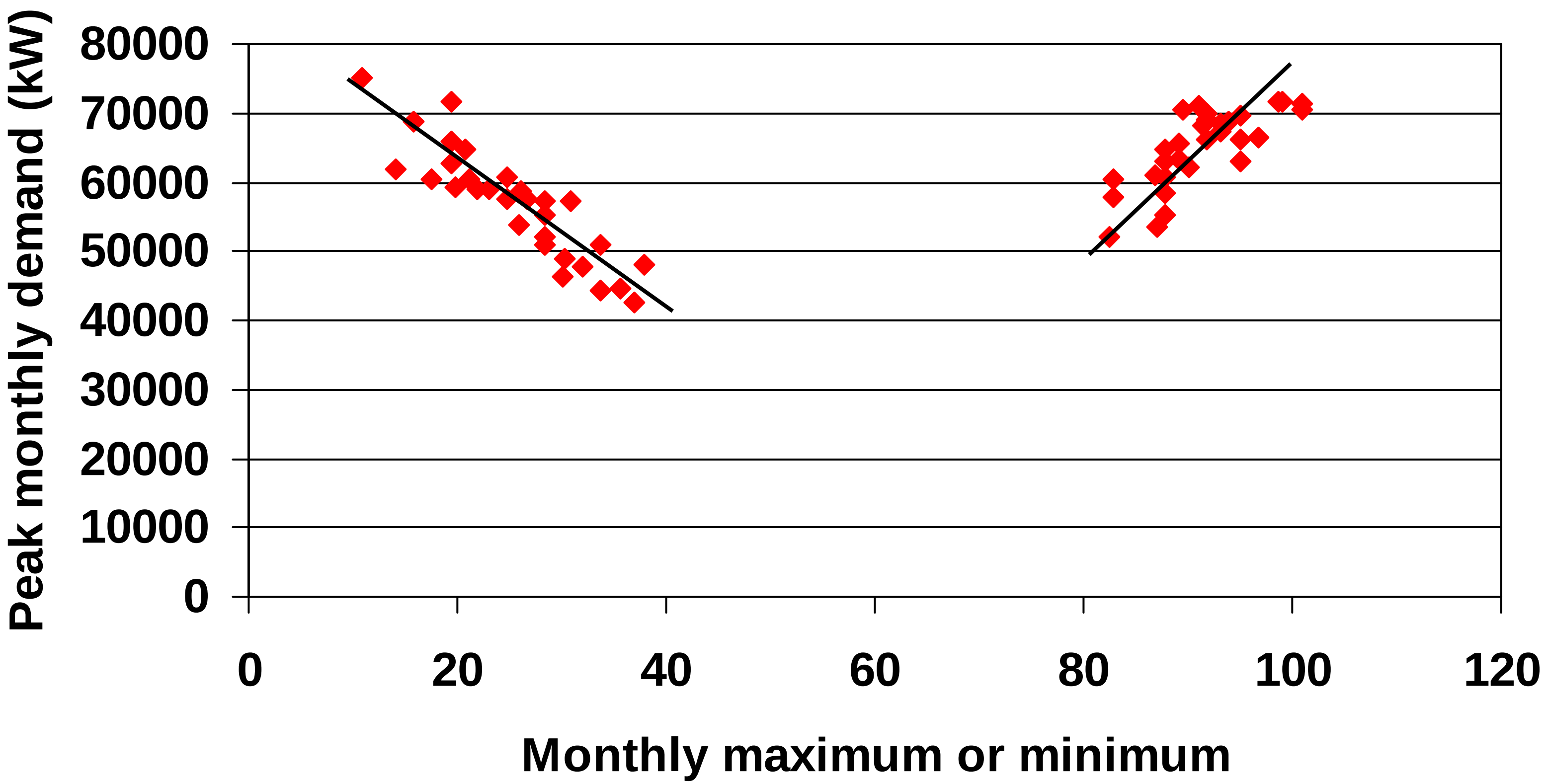
In the case of electrical use, model must account for “load creep” or savings would quickly disappear



For electrical use, a demand model will likely also be required

- Some energy cost savings are due to a reduction in demand charges
- For an M&V plan like this, we must predict what demand would have been in the absence of the CHP system
- This can be difficult to do
- Peak demand is generally coincident with extreme outdoor temperatures, but not always so

Always look at the data: predicting peak demand may not be as difficult as you think



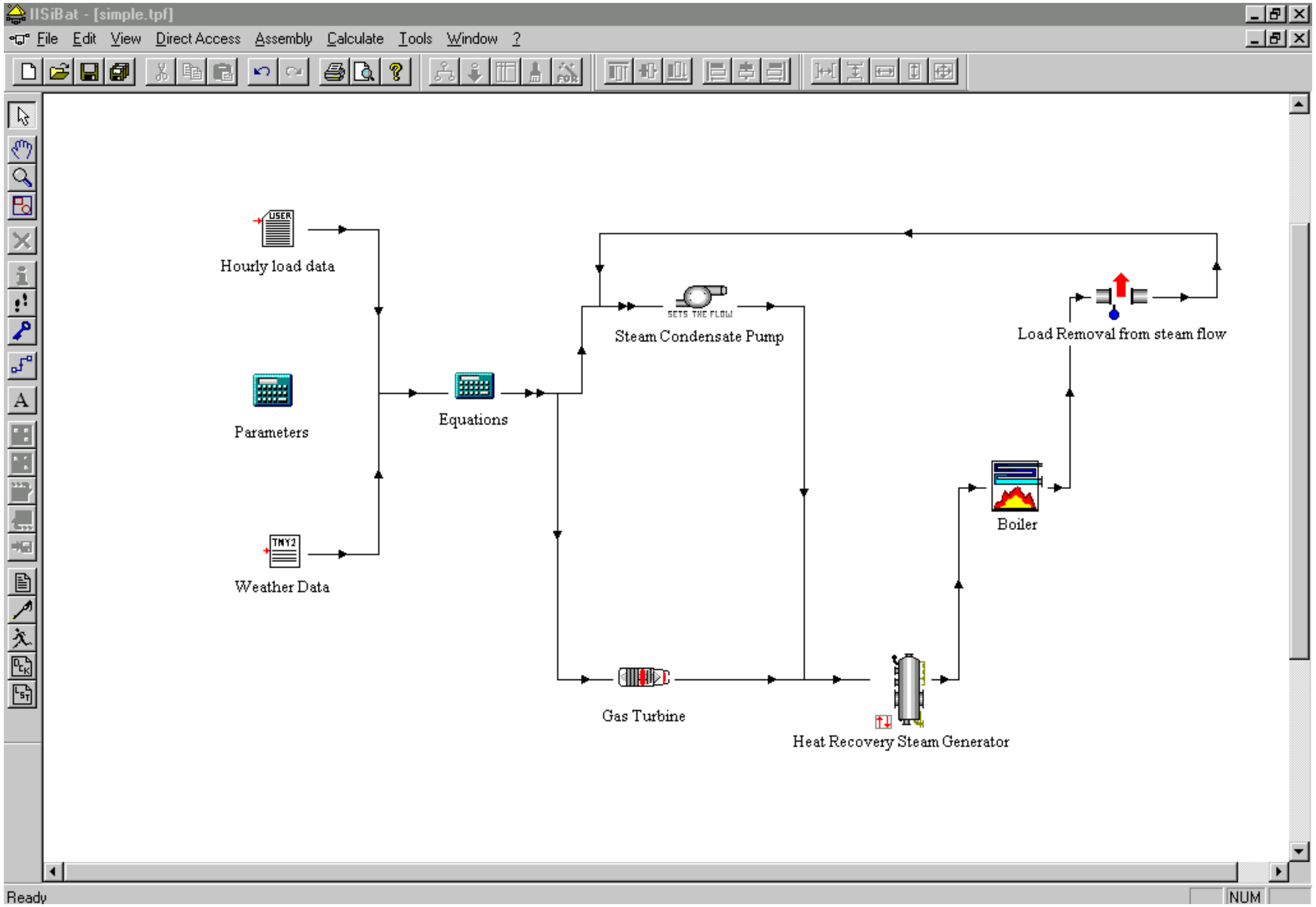
Then, every time utility bills are received do the following:

- Record billed kWh and therms
- Determine number of days in billing period
- Calculate HDD and CDD to proper base temperatures for the billing period
- Calculate baseline gas and electric use from correlations
- Use appropriate rates to determine cost of baseline gas and electric use
- Subtract billed gas and electric to determine energy cost savings
- M&V report shows that savings calculated this way are greater than or equal to guaranteed savings

Option D (Calibrated Simulation) M&V can also be applied to CHP projects

- In some situations, neither “one-for-one replacement” nor “net energy analysis” methods provide reliable results
  - Difficult to determine cost of displaced energy (as in previous example)
  - Available utility data not applicable (construction or demolition of buildings, for example)
- Simulation models may be used to estimate energy and energy cost savings

Example TRNSYS Simulation



Developing an Option D M&V plan

- Develop baseline simulation model
- Calibrate to site-monitored data (install temporary equipment if necessary)
- Finalize baseline fuel and electrical use model
- Implement CHP equipment in software
- Predict post-installation fuel and electrical use
- Annually, show that CHP system continues to operate per assumptions in post-retrofit model

Conclusions

- Purpose of M&V for a CHP project is to show that energy cost savings are consistent with guarantees
- CHP systems have the advantage that they actually produce energy, and this energy production can be measured
- If the economic value of the energy produced by the CHP system can be easily determined, then M&V is relatively straightforward
  - Calculate the value of the net energy produced
  - Show that it is consistent with guaranteed savings

Conclusions

- If economic value can not be determined directly, modeling may be necessary
  - Develop baseline fuel and electrical use model based on historical utility bills
  - Subtract actual billed usage from usage predicted by baseline models
  - Show that energy cost savings is consistent with guarantees
- Calibrated simulations can also be used to verify savings guarantees

Where do we go from here?

- Examination of available M&V plans for CHP projects shows that more work is needed in this area
- Some current plans do not provide sufficient verification that guaranteed savings are being achieved
- What is needed are straightforward methods that compare what energy costs “would have been” in the absence of CHP with what costs actually are
- That is the only definition of savings that makes sense, and it should be the driving factor in M&V for CHP